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Traffic Model Based Optimization of Dredging Plan: Yangon River Channel

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ABSTRACT

The paper presents about the simulation based optimization of channel dredging plan. Yangon River channel is used as the research object. Firstly the realistic traffic simulation model of the channel in its current situation is developed with Arena simulation software. Then the model is executed in several assumptions of different available channel depths. Among the several outputs, average port time generated from each scenario is used as the optimizing parameter. Assumptions considered are 0.5 meter, 1.5 meter and 2 meter channel deepening with 10 years, 15 years and 20 years growth rate respectively. The minimum of the summation of average port times for all deepening assumptions is used as the objective function. Decision parameter here is simply yes or no; if deepening work should be commenced within the intended time interval the answer is yes and otherwise the answer is no. With this optimization model, this study answers which deepening assumption should be carried out in which time interval for the optimal port time.

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1. Introduction

The Port of Yangon is the premier port of Myanmar and handled about 90 % of the country's exports and imports [Myanmar Port Authority (2014)] and the country international trade is growing rapidly. To cope with the growth of seaborne cargo traffic and to lessen the logistics cost in maritime trade by providing accessibility for bigger vessels to the ports, Myanmar Port Authority (MPA) is taking initiatives to improve the Yangon River access channel, while development of Thilawar Port is a key solution [Min and Kudo (2012)]. In improving the access channel, dredging the two sand bars shown in Figure 1 is the main task and this study investigate the optimal dredging plan to deepen the available channel depth at these designated bars namely Outer Bar and Inner Bar.

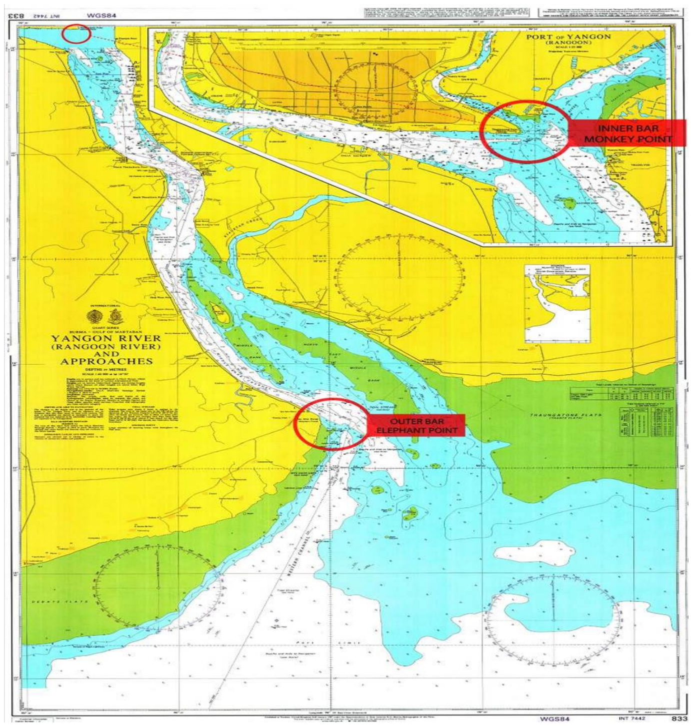


Figure 1. Locations of the two Bars

2. Trade and Vessel Traffic and Developing Trend

The following data of annual import, export and number of vessel calls to Yangon port from 2001 to 2010 shown in Table 1 is available with the merit of Myanmar Port Authority. On these data, linear regression analysis is made and trade and vessel traffic growth for Yangon River channel is forecasted up to Year 2030 and shown in Table 2. This work has been already published in the Journal of International

Academic Research for Multidisciplinary (JIARM) with the title "Forecasting the International Trade and the Ship Arrival Rate for Yangon Port" [Win and Xiao (2013)].

Table 1. Current amount of annual import, export and vessel calls to Yangon port (2001 to 2011)

Fiscal Year	Number of Vessel	Import (Metric Tonnage)	Export (Metric Tonnage)	Total (Metric Tonnage)
2000-01	915	4381934	6286311	10668245
2001-02	915	4978070	5201138	10179208
2002-03	1188	4834614	6005218	10839832
2003-04	1045	4609417	5190954	9800371
2004-05	1517	4773347	5207580	9980927
2005-06	1252	4724960	5513755	10238715
2006-07	1219	5332093	5622693	10954786
2007-08	1529	5619362	6240124	11859486
2008-09	1739	6165473	6150475	12315948
2009-10	2016	6655370	9492079	16147449
2010-11	2155	6131245	12307396	18438641

Table 2. Forecasted annual import/export and vessel calls (2011 to 2030)

Fiscal Year	Number of Vessel	Import/ Metric Ton	Export/Metric Ton
2011-12	2113	6492915.07	9395342.8
2012-13	2231	6693160.24	9851873.83
2013-14	2348	6893405.40	10308404.85
2014-15	2466	7093650.56	10764935.88
2015-16	2583	7293895.73	11221466.91
2016-17	2701	7494140.89	11677997.94
2017-18	2818	7694386.05	12134528.96
2018-19	2936	7894631.22	12591059.99
2019-20	3053	8094876.38	13047591.02
2020-21	3171	8295121.55	13504122.05
2021-22	3288	8495366.71	13960653.07
2022-23	3406	8695611.87	14417184.10
2023-24	3524	8895857.04	14873715.13
2024-25	3641	9096102.20	15330246.15
2025-26	3759	9296347.36	15786777.18
2026-27	3876	9496592.53	16243308.21
2027-28	3994	9696837.69	16699839.24
2028-29	4111	9897082.85	17156370.26
2029-30	4229	10097328.02	17612901.29

3. Modeling vessel traffic and verification of the model

Simulation is the process of designing a model of a real or imagined system and conducting experiments with that model. The purpose of simulation experiments is to understand the behavior of the system or evaluate strategies for the operation of the system [Roger (2000)]. Simulation modeling is a common paradigm for analyzing complex systems. In a nutshell, this paradigm creates a simplified representation of a system under study. The paradigm then proceeds to experiment with the system, guided by a prescribed set of goals, such as improved system design, cost–benefit analysis, sensitivity to design parameters, and so on [Tayfur and Benjamin (2007)]. In classical thinking there are three types of simulation; discrete event, continuous, and Monte Carlo [Mike and AZ (2010)]. The majority of modern computer simulation tools (simulators) implement a paradigm, called discrete-event simulation (DES). Arena is discrete event simulation and automation software developed by Systems Modeling and acquired by Rockwell Automation. It uses the SIMAN processor and simulation language. In this study, Arena simulation software is used for modeling the vessel traffic in Yangon River channel.

The main goal behind the model development is to constitute an accurate platform to study key issues regarding the Yangon River channel's operation. The detailed simulation model of the vessel traffic in Yangon River channel is developed for the whole channel from the Pilot Station (Lantharyar Fairway) where embarkation of pilot is took place for navigation of the vessel along the channel to the inner most Port of Yangon (Inner Harbor). Three designated routes of Lantharyar Fairway to Inner Harbor, Lantharyar Fairway to Outer Harbor (Myanmar International Terminal, Thilawar (MITT)) and Lantharyar Fairway to NEA are consider and applied in the model. To develop the simulation model, Arena 14.5 of Training & Evaluation Mode (Student) version simulation software is used. Figure 2 illustrates the designated routes.

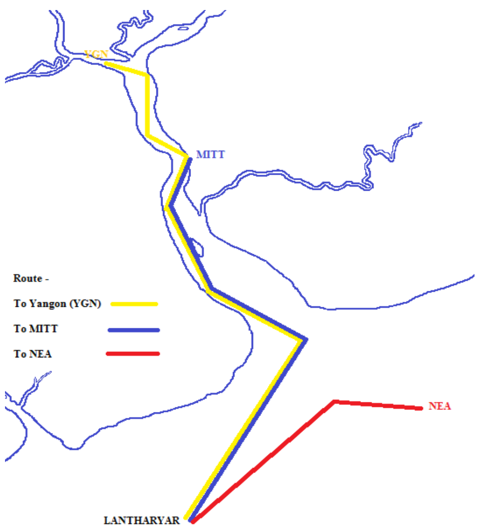


Figure 2. Main routes in Yangon channel

3.1 Model structure and development

Figure 3 illustrates the structure of the simulation model. The figure is comprised of three segments. The top and the bottom segments show the procedure flows of arrival and exit whereas the middle segment depicts the processes and delays in the port system. Arriving vessel would be generated by randomized vessel arrival generator and the generated vessel would be assigned its particulars and designated port with fixed distribution pattern upon its arrival. After all necessary particulars have been assigned; the vessel would be treated with the inbound tidal regulation in accordance with the time of the tide generated from the tide generator. When the tidal regulation permits, the available pilot will bring the vessel and send to the designated terminal in accordance with the navigation rule and terminal reservation. At the terminal, the vessel is allowed to commence its port operation and after the operation has finished, the vessel would be treated again with outbound tidal regulation and the available pilot will serve the vessel with the same procedure as inbound process and send it back to the port exit station, then the vessel exit from the system. All the statistics regarding with the vessel in system would have been tracked and recorded in the system. The same procedure is applied to all vessels.

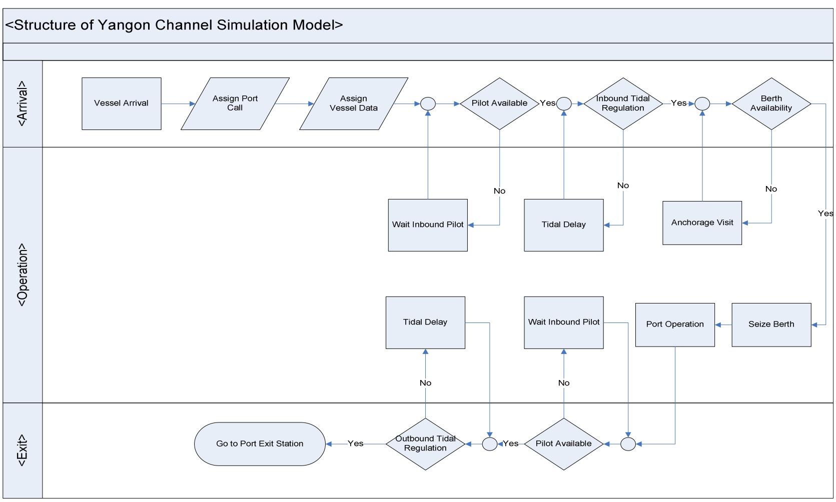


Figure 3. Structure of simulation model

Components include in the model are vessel arrival generator, pilot generator, sailing & port operation and tide generator. Detail vessel movement data for three routes namely Line 1, Line 2 and Line 3 have been survey for one month on August, 2012 and historical data of 2001 to 2013 are obtained from MPA and properly applied in the model. The simulation model involves all vessel calls, their drafts and GRT, arrival patterns, terminal operation, anchorage holding and delay, and also incorporates all the tidal activity and navigational rules as explained in “General Information on Ports and Shipping in Myanmar” [Logistics Cluster (2014)]. The high level view of model logic is shown in Figure 4.

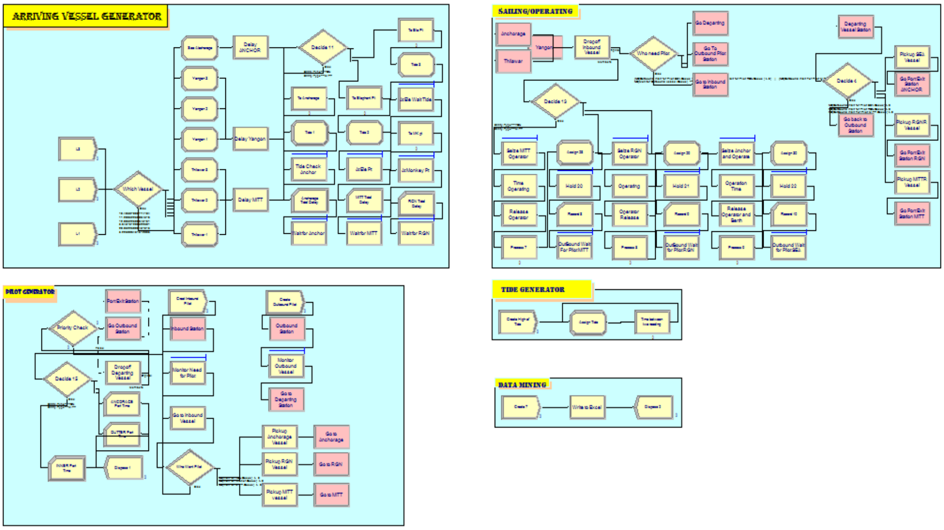


Figure 4. High level view of model logic

3.2 Verification and validation

The model is verified in several steps to check if it is working the way it is intended to. The model is developed in sub-modules and each module is individually examined. Via animated interface shown in Figure 5, operation of the overall system is followed and synchronization of events is also observed and verified. The tracing approach is another method used throughout the model development phase. Detailed report of entity processing is compared with the data in hand and manual calculations through tracing in order to check if the logic implemented in the model is as intended.

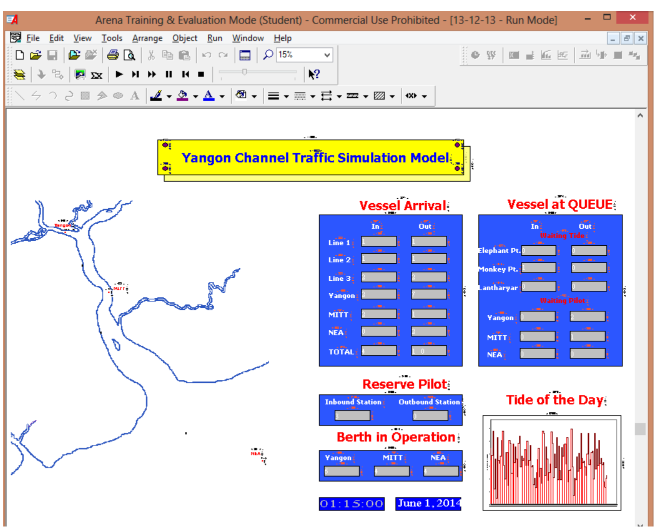


Figure 5. Animated view of simulation model

For validation purposes, several tests are performed and various key performance measures are observed to see if they are close to their counterparts in reality. The simulation results of 50 replications for 20 years representing the current situation in Yangon River channel are compared to the observations of the port calls between 2010 and 2013 and port time on August, 2012. Figure 6 shows the comparison between actual data and simulated data of port calls and port times. The annual vessel calls generated from the model lies within 5 % difference from the actual value. The average port time of vessel to MITT and NEA anchorage lie within 7% difference from the actual value. Only the average port time of the vessel to inner harbor exceed the 10% difference from the actual value. On the other hand, since the port call to each port area is generated using a distribution specific to that port area, discrepancy from the actual data is only due to randomness. As a result of these comparisons between the actual data and simulation results, the simulation model built to mimic the vessel traffic in Yangon River channel is considered to have close representation of the actual system to perform the analysis.

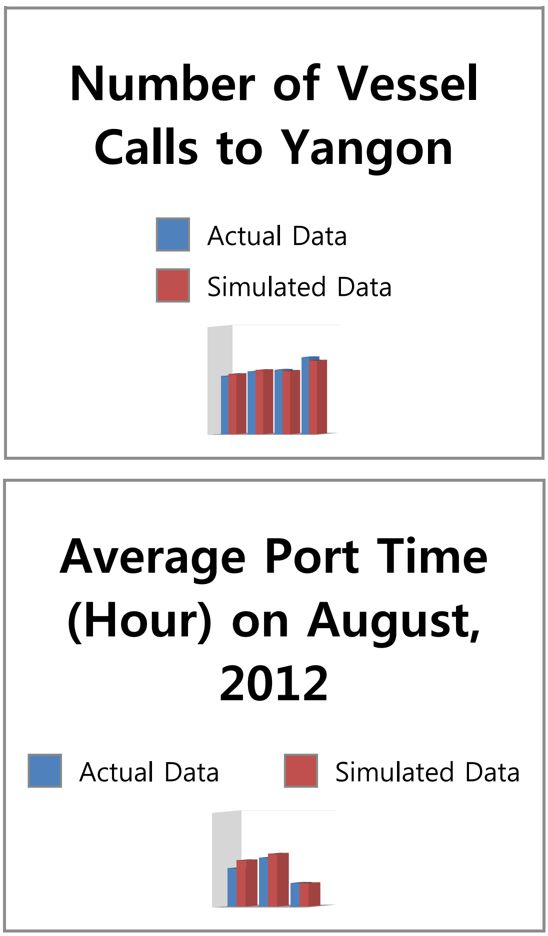


Figure 6. Yearly port calls and port times comparisons

4. Optimizing the channel dredging plan

This secession presents the time stamped deepening steps investigated via simple optimization model. Firstly, trade and vessel traffic growth assumption is applied to the model. Based on the forecasted growth rate data discussed in section 2, vessel arrival and trade growth rate for every 5 years can be assume as given in Table 3 and is applied on top of the validated model.

Table 3. Assumed vessel arrival growth rate (2011 – 2030)

Item	% Increase Rate			
	1st 5 Years	2nd 5 Years	3rd 5 Years	4th 5 Years
Vessel	22.24%	15.39%	15.43%	13.34%
Import	12.33%	10.98%	9.89%	9.00%
Export	19.44%	16.27%	13.99%	12.28%

Then the available channel depth is assumed to be deepened 0.5 meter without allowing larger vessel as the first step, 1.5 meter with allowing larger vessel as the second step and 2 meter with allowing larger vessel as the final step and the model is run with assumed growth rate of 10 years, 15 years and 20 years. Average port time of each deepening assumptions for respective growth rate generated from the developed traffic model is shown in Table 4.

Table 4. Generated average port times

Average Port Time (Hour)	10 Year	15 Year	20 Year
0.5 m Deepen	515.79	517.24	515.5
1.5 m Deepen	519.52	517.27	551.37
2 m Deepen	525.63	519.06	514.34

Optimization objective could be simply to minimize the cost of production or to maximize the efficiency of production. A traditional way to develop answers to optimization problems is to propose a number of choices from various options for the controlled parameters. Then the processes under investigation are simulated under these options, and the results are compared [Josef and Anna (2014)].

An optimization model has three main components of objective function, decision variables and constraints. The formulation of an optimization problem begins with identifying the underlying variables, which are primarily varied during the optimization process. Objective function is the function that needs to be optimized. The solution to the optimization problem is the set of values of the decision variables for which the objective function reaches its optimal value. Constraints in the optimization model restrict the values of the decision variables. In the following sections, natures of the objective function, decision variables and constraints are presented and discuss how these parameters are fixed for this optimization problem.

4.1 Decision variable

Finding the optimal values of the decision variables is the goal of solving an optimization model [Extreme Optimization Numerical Libraries for .NET (2014)]. A decision variable is a quantity that the decision-maker controls [OptTek Systems, Inc (2014)]. Decision variables usually measure the amounts of resources used (such as money to be allocated to some purpose) or the level of various activities to be performed (such as the number of products to be manufactured, or the number of gallons of a chemical to be blended) [FrontlineSolvers (2014)]. This study concerned the suitable time of commencing the appropriate deepening work. In accordance with the scenarios applied to developed traffic model, there has considered three different deepening work assumptions of 0.5 meter deepening without allowing larger vessel, 1.5 meter deepening with allowing larger vessel and 2 meter deepening with allowing larger vessel. In this optimization model, it is assumed that the time of commencing each deepening is initially unknown and the model will investigate the most suitable time of commencing for optimal channel performance. Thus it is need to define the commencing time as decision variables. Because it is known from the traffic simulation model analysis that the physical condition of the channel is still suitable for next five years, the different times of commencing such as within 10 years, within 15 years and within 20 years are defined as decision variable. Decision parameter here is simply yes or no that is if should be commenced within the intended time interval the answer is yes and otherwise the answer is no. Mathematically it can simply represent with binary expression of “0” and “1”. If the answer is yes then the decision variable is “1” and otherwise “0”.

Because there has three different options of deepening work and three different time interval, totally there has nine decision variable of “Yes” or “No” and the following Table 5 represents the decision table.

Table 5. Decision variables table

Depth Assignment	Within 10 Year	Within 15 Year	Within 20 Year
0.5 m Deepen	0	0	0
1.5 m Deepen	0	0	0
2 m Deepen	0	0	0

4.2 Objective function

The goal of the optimization process is to find the parameter values that result in a maximum or minimum of a function called the objective function. Objective function is a mathematical expression describing a relationship of the optimization parameters or the result of an operation (such as simulation) that uses the optimization parameters as inputs. The optimization objective is the objective function plus optimization criterion. The latter determines whether the goal of the optimization is to minimize or maximize the value of the objective function [AnyLogic (2014)].

This study concerns the channel performance measures. In considering channel performances, the volume of traffic that the channel can accommodate within a specific time is the most prominent factor. It can be regard that the more the traffic volume can accommodate, the higher the channel performance is. This study only concerns the depth of channel that influencing the channel performance. It is assumed that the different available channel depth will influence the ship waiting time for tide and navigation efficiency. In this regard, average port times of vessels in the channel will not be the same for all available depths and these are regarded as the important factors in measuring channel performance. Thus, it can be understand that by reducing average port times of vessels, the volume of traffic in the channel can be maximized. Accordingly the objective of this model can be explained as to minimize the total average port time for optimal channel performance.

To optimize the channel performance, it is need to minimize the grand total of port time for all assumed depths and assumed commencing years. Therefore the objective function of this optimization model can be regarded as the minimum of the product of Table 4 and Table 5, and it can be expressed in mathematically as:

4.3 Constraints

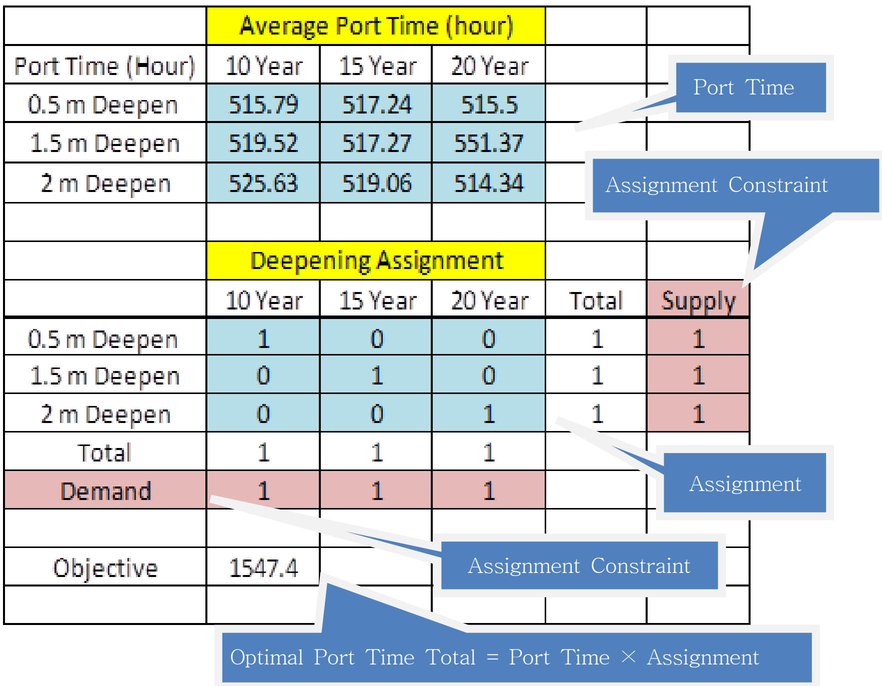
In formulation of optimization problem, constraints are also important factors and these represent some functional relationships among the variables and other parameters satisfying certain physical phenomenon and certain resource limitations. Constraints are logical conditions that a solution to an optimization problem must satisfy. Many constraints are determined by the physical nature of the problem. A special type of integer constraint specifies that a variable must be binary -- either 0 or 1 -- at the final solution. Binary variables can be used to model "yes/no" or "go/no-go" decisions and are very useful in a variety of modeling situations. In this study also, binary integer variable is used as constraints because the problem concerned is a decision problem and only one action can implement at a time. For example, while 0.5 meter deepening is applied to within 10 year time interval, the other two deepening actions of 1.5 meter deepening and 2 meter deepening cannot implement within the same time interval. Thus, demand for total depth assignments for each time interval is limited to “1” implementation so that within a specific time interval only one deepening assumption can be implemented. On the other hand, supply for total implementation of each deepening assumptions is also limited to “1” so that each deepening assumption can only be assigned once throughout the planning horizon of 10 year to 20 year. Tabulated representation of the constraint limitation idea is shown Table 6.

Table 6. Tabulated representation of constraint limitation

Depth Assignment	10 Year	15 Year	20 Year	Total	Supply
0.5 m Deepen	0	0	0	0	1
1.5 m Deepen	0	0	0	0	1
2 m Deepen	0	0	0	0	1
Total	0	0	0		
Demand	1	1	1		

4.4 Optimization

An optimization algorithm is a procedure which is executed iteratively by comparing various solutions till an optimum or a satisfactory solution is found. Problem has been formulated with the objective function, decision variables and constraints which have discussed in the above secessions and optimization process is carried out with the excel solver. The following Figure 7 depicts the optimization model.



	Average Port Time (hour)				
Port Time (Hour)	10 Year	15 Year	20 Year		
0.5 m Deepen	515.79	517.24	515.5		
1.5 m Deepen	519.52	517.27	551.37		
2 m Deepen	525.63	519.06	514.34		
	Deepening Assignment				
	10 Year	15 Year	20 Year	Total	Supply
0.5 m Deepen	1	0	0	1	1
1.5 m Deepen	0	1	0	1	1
2 m Deepen	0	0	1	1	1
Total	1	1	1		
Demand	1	1	1		
Objective	1547.4				

Figure 7. Optimization model

Minimum of average port time total is regarded as objective outcome and accordingly the object function is set as the product of assignment into port time. Total assignments are limited by demand and supply constraints and all the assignment decision parameters are set as binary integer of “0” and “1”. “1” represents “Yes” and that shows the deepening assumption should commence in that time interval. Optimal dredging plan for the channel is solved out with this model in Excel Solver and the optimal results are as shown in figure. According to the results, the optimal port time of 1547.4 hours can be achieved by commencing 0.5 meter channel deepening work within next 10 years, 1.5 meter channel deepening work within next 15 years and 2 meter channel deepening work within 20 years planning horizon respectively.

5. Conclusion

With this study, a realistic traffic simulation model to investigate the conditions of the channel has been developed as an analysis tool for improvement planning strategy. With this developed traffic model, optimal dredging plan has been successfully solved out. The finding is hoped to be useful in actual implementation of Yangon River channel improvement works.

Actually the model is developed for multi-purpose. Thus, the most valuable product of this study is the simulation model itself. It can be used to support decision making process in various areas of interest and to answer "How-if" questions since it enables to analyze the channel with different assumptions in accordance with the desired upgrading plan.

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